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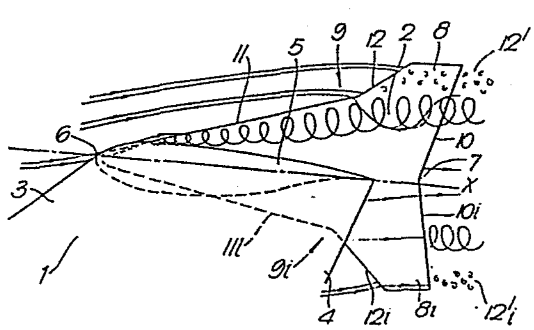
(54) Aircraft wing and winglet arrangement.

(57) An aircraft wing (1) has a winglet (2) extending from the tip to reduce drag and thereby improve the efficiency of the aircraft. Hitherto such winglets (2), although they have succeeded in reducing drag, they have also increased the wing bending moment at high coefficients of lift sufficient to require a strengthened and therefore heavier wing. Moreover, they have suffered flow breakaway at such high coefficients of lift and have therefore incurred aircraft control problems. A winglet according to the present invention, is of high sweep back and low Aspect Ratio. It resulting increase in the bending moment on the wing is relatively low even at high lift coefficients and since it changes from conventional attached flow to vortex flow and therefore does not experience random flow breakaway at high lift coefficients, it does not harm aircraft control.

Fig.4.



EP 0 122 790 A1

AIRCRAFT WING AND WINGLET ARRANGEMENT

This invention relates to aircraft wings and winglets therefore.

It is known that providing a winglet at the tip of an aircraft wing can significantly reduce the lift induced drag compared with a wing not so provided. Hitherto, such winglets have tended to increase the bending moments experienced by the wing thus necessitating a strengthened and therefore heavier wing. Also, such winglets have tended to stall, that is to say, experience flow breakaway over their surfaces, when high lift conditions are experienced by the wing proper, for example during take off, causing sudden lift losses, relatively large increases in drag, and attendant handling problems for the aircraft.

Accordingly, two major objects of the present invention are

(a) to reduce the lift induced drag of an aircraft wing compared with a similar wing not so fitted by the addition of a winglet without so increasing the bending moments experienced by the wing that little or no strengthening is required, and

(b) to prevent or at least minimise flow breakaway over the winglet so that no handling problems are caused by fitting the winglet.

According to the invention, an aircraft wing includes main wing means having a median plane and a wing tip region of specified chord having a leading edge region and a trailing edge region, and winglet means extending from said wing tip region, the winglet means having a root region with both a forward extremity and a rearward extremity in the region of the median plane, the forward extremity of the winglet means lying at or rearward of the leading edge region of the main wing means, a tip region remote from the median plane, a leading edge region extending between the forward extremity and the tip region of high sweep back over at least part of its length at or near the root region, and a trailing edge region extending between the rearward extremity of the root region and the tip region, the ratio of the square of the distance from the tip region to the root region to the area bounded by and including the root region, the tip region, the leading edge region and the trailing edge region being 1.5 or less.

By this arrangement, such a winglet provides a drag reduction compared with the same wing not so equipped. In particular, the winglet can be arranged to provide its most useful drag reduction at a particular lift coefficient of the wing on which it is to be attached, for example that lift coefficient suitable for long range cruise, but when the coefficient of lift of the wing is increased, for example for in flight manoeuvres, the rate and hence the total increase of wing bending moment as a direct result of the presence of the winglet is much lower than hitherto.

Naturally, although described for ease of comparison with reference to an existing wing, this advantage is applicable to wings designed from the outsdet to include a winglet according to the invention.

Furthermore, in conditions when previously known winglets would tend to experience flow breakaway, the winglet of the present invention develops strong vortex sheets which, by flowing over its surfaces prevent random flow breakaway. Such conditions leading to flow breakaway on previous winglets occur when the coefficient of lift of the wing is increased by increasing incidence and there is considerable flow from the undersurface to the upper surface around the wing tip.

The arrangement also ensures that ice does not readily form on the winglet, and, if it does form, it merely causes vortex sheets to be formed with no significant effects on aircraft handling.

Some embodiments of the invention applied to a subsonic transport aircraft are described by way of example with reference to the accompanying drawings in which:-

Figure 1 is a perspective view of an aircraft wing tip looking outboard, the illustrated air flow being typical of that in cruising flight,

Figure 2 is a similar view to that of Figure 1 but with the illustrated air flow being typical of that in high lift coefficient flight,

Figure 3 is a similar view to that of Figure 1 but showing an alternative embodiment again in cruise flow conditions.

Figure 4 is a similar view to that of Figure 3 but showing the alternative embodiment in high-lift coefficient flight,

Figure 5 is a view of the embodiment of Figures 3 and 4 but illustrating the incorporation of housing means,

Figure 6 is a view on Arrow VI of Figure 5,

Figure 7 illustrates a true side view of the embodiment of Figures 1 and 2 looking inboard,

Figure 8 illustrates a true side view of the embodiment of Figures 3 and 4 looking inboard,

Figures 9a, b, c, are similar views to that of Figure 7 showing alternative embodiments,

Figure 10 is a similar view to that of Figure 8 showing an alternative embodiment,

Figure 11 is a front view of a wing tip with winglet illustrating various angles of cant,

Figure 12 is a graph illustrating (change of wing bending moment) divided by (dynamic pressure) plotted against (wing lift increase) divided by (dynamic pressure) for three forms of wing tip arrangement relative to an unmodified wing, and,

Figure 13 is a graph showing (drag reduction) divided by (dynamic pressure) plotted against (wing lift increase) divided by (dynamic pressure) for the same three forms of wing tip arrangement relative to the unmodified wing.

In each case (wing lift) divided by (dynamic pressure) is proportional to coefficient of lift. Referring initially to Figures 1 and 2, an aircraft wing includes a main wing 1 of which only a tip region is shown and a winglet 2 extending from the tip region both upwards and downwards from a median plane X - X of the wing. The median plane X - X is that plane extending through or near the foremost and rearmost extremities of the wing.

The wing tip has a leading edge region 3 and a trailing edge region 4.

Although illustrated as extending both the upwards and downwards directions from the median plane X - X a winglet 2 may extend only in one of the directions. Moreover, although illustrated as symmetrically disposed about the median plane when extending in both directions, a winglet 2 may not be necessarily so.

As illustrated in Figures 1 and 2, a winglet 2 has a root region 5 with a forward extremity 6 and a rearward extremity 7, an upper tip region 8 and an upper leading edge region 9 extending between the forward extremity 6 and the tip region 8. The leading edge region is of high sweepback, in this case being at a constant angle Q typically 70^{o} measured from the normal to the median plane X - X. A trailing edge region 10 extends from the rearward extremity 7 to the tip region 8. The range of suitable angles and other parameters are disclosed with reference to Figure 7. The aspect ratio (AR) of that portion above the median plane X - X, that is to say, the ratio of the square of the distance from the tip region 8 to the root region 5 when measured normal to the median plane (i.e. the square of the semi-span) and the area bounded by and including the root region 5, the tip region 8, the leading edge region 9 and the trailing edge region 10 (i.e. the gross area above <u>or</u> below the median plane X - X) is typically 0.45. It is thus of low aspect ratio. The overall aspect ratio for the winglet extending both above <u>and</u> below the wing median plane X - X is typically 0.90.

In this embodiment, that part of the winglet 2 extending below is a mirror image of that extending above. The components thereof are given the suffix "i", signifying "inverted".

The sweep angle of the trailing edge region 10 is selected to provide adequate chord length of the root region 5 for structural purposes and/or to aid aerodynamic design of the gully between the main wing 1 and the winglet.

Referring now to Figures 3 and 4, a winglet 2 has similar configuration to that of Figures 1 and 2 and is thus allocated like reference numerals for like items.

It is only in respect of the leading edge regions 9 and 9i that significant difference is present. The region 9 and 9i are each formed of an inboard region 11 lying near the root region 5 and an outboard region 12 lying near the tip region 8. The inboard region 11 is of high sweepback angle Q1 typically 70^{o} measured from the normal to the median plane X - X whilst the outboard region 12 is of less sweepback angle Q2, typically 45^{o}.

The aspect ratio of the portion above the median plane X - X is typically 0.80 and for the whole winglet extending above and below the median plane is typically 1.60. Although this aspect ratio is naturally greater than that for the embodiment of Figures 1 and 2, it is still defined as 'low'.

The inboard region 11 typically extends over the inboard 60% of the distance between the tip region 8 and

8i and the root region 5 and 5i, whilst the outboard region 12 typically extends over the outboard 40%. As is shown in Figure 4, it is possible to allow the flow over the outboard regions 12, 12i and the tip regions 8, 8i to break away as indicated by the stream of bubbles 12', $12'_i$) at high lift and/or high speed conditions. The vortex flow over the inboard regions 11, 11_i are reflective to keep this break away flow limited in extent and thus minimise any effect on aircraft handling. This arrangement has advantage in that aerodynamic load on the winglet is reduced in otherwise high load conditions of the wing and winglet.

Figures 5 and 6 illustrate how the root region 5 of the winglet 2, irrespective of the shape of its leading edge region 9, 9i, can be extended inboard to modify the gully region between the surface of the main wing 1 and the inboard surface of the winglet 2 to improve the quality of flow in that region. Conveniently, this extended root region can provide a housing 13 for an item such as navigation light, antenna, or fuel jettison duct.

Figure 6 illustrates how the leading edge regions 9, 9i, and trailing edge regions 10, 10i, and indeed the winglet as a whole, can be cambered to enhance particular flow characteristics over the winglet 2 at certain operating conditions of the main wing. This is irrespective of the fitting of the housing 13. As is shown, the portion of the winglet lying above the median plane X - X has its leading edge and/or its trailing edge regions 9, 10 cambered to cause a median line 44, (that is to say a line which, at any chordwise station, lies equidistant between the opposite surfaces of the winglet) to droop in an outboard direction of the main wing whilst that portion lying below has its leading edge and/or its trailing edge regions 9_i, 10_i cambered to cause the median line 44_i to droop in an inboard direction.

Figure 7 illustrates an embodiment of the arrangement of Figures 1 and 2 on which typical and limiting values of dimensions are given using the specified chord C_T of the main wing tip as reference.

Thus:-

Parameter	Typical Value	Limiting Values Upper Limit	Lower Limit
Q, Q_i	70^o	85^o	50^o
h, h_i	$0.17C_T$	$0.5C_T$	-
L	$0.62C_T$	$1.25C_T$	-
P	$0.05C_T$	$0.5C_T$	$- 0.75C_T$
AR (when span = h + h_i)	0.90	3.0	-

Figure 8 illustrates an embodiment of the arrangement of Figures 3 and 4 on which typical and limiting values of dimensions are given again using the specified chord C_T of the main wing tip as reference.

Thus:-

		Limiting Values			
Parameter	Typical Values	Upper Limit	Comments	Lower Limit	Comments
Q_1, Q_{1i}	70^o	85^o	When at 85^o applied, over at least inner 10% of semi-height (h_2)	50^o	
Q_2, Q_{2i}	45^o	-		35^o	When at 35^o applied, over at most outer 20% of semi-height (h_2)
h_1 h_{1i}	0.6 h_2	h_2		$0.3h_2$	
h_2 h_{2i}	$0.33C_T$	C_T		-	
L	$0.85C_T$	$1.25C_T$		-	
P	$0.05C_T$	$0.5C_T$		$-0.75C_T$	
AR (when span = h_2+h_{2i})	1.6	3.0		-	

In each case, the aspect ratio (AR) is for a winglet which is symmetrical above and below the median plane X - X, but such symmetry is not essential.

Figures 9*a*, *b* and *c*, and Figure 10 show various alternative winglets by way of example. These examples are not exhaustive and are illustrated merely to show some embodiments of the invention.

In Figure 9*a*, $P = 0$ and $L = 0.6C_T$, in Figure 9*b* $P = -0.36\ C_T$ and $L = 0.6C_T$, and, in Figure 9*c* $P = 0$ and $L = C_T$.

As can be seen in Figure 9*a*, $h = h_i$, Figure 9*b*, $h > h_i$ and in Figure 9*c*, $h > h_i$.

In Figure 10, which illustrates a version of the embodiment of Figures 3 and 4 with the intersections of the twin leading edge regions 11 and 12 and the intersection of the region 12 with the tip region 8 are smoothly blended. In this embodiment $P = 0.10\ C_T$ and $L = 0.95\ C_T$.

Figure 11 illustrates how the upper and lower regions of the winglet 2 may be canted with respect to one another, both inboard or outboard, or they may be co-planar but still canted.

Figures 12 and 13 are included to graphically show how a winglet of the present invention compares with two other wing tip devices.

In Figure 12, graph 20 illustrates the change of main wing bending moment with lift increase due to the presence of a wing tip extension in the form of an increase in span of the main wing. As can be seen, the slope is relatively steep.

Graph 21 illustrates the change of main wing bending moment with lift increase due to the presence of a winglet of relatively lower sweepback and relatively higher aspect ratio than the winglet of the present invention, that is to say graph 21 relates to a known winglet. As can be seen, the slope is less steep than graph 20. However, at region 22, stalling of the winglet can occur with attendant flow breakaway. Thus the curve dips sharply and is indicative of potential handling problems.

Graph 23 illustrates the change of main wing bending moment with lift increase due to the presence of a winglet according to the invention. As can be seen, the slope is less steep than either of the other two graphs. It follows one slope, region 24, where conventional attached flow is taking place, and subsequently, after a transition period, region 25, where a mixture of flows may be present, it follows a somewhat steeper slope, region 26, where the attached flow is replaced, at least to a large extent, by a stable leading edge generated vortex flow. These distinct types of flow are illustrated in Figures 1, 3 and 2, 4 respectively and a brief discussion with respect to these Figures follows below.

In Figure 13, graph 30 illustrates the drag reduction with lift increase due to the presence of the same wingtip extension as that of graph 20. As can be seen, there is a high and increasing drag reduction, but its associated bending moment increase renders such an arrangement undesirable.

Graph 31 illustrates drag reduction with lift increase due to the presence of the same, known, winglet as that of graph 21. As can be seen, there is a high and increasing drag reduction, but at region 32 (associated with region 22) flow breakaway can occur leading to random but massive drag increases and hence likely aircraft handling problems. This, together with the relatively high increase in bending moment, renders such an arrangement potentially undesirable.

Graph 33 illustrates drag reduction with lift increase due to the presence of a winglet according to the invention, that is to say a similar winglet to that of the graph 23. As can be seen at region 34, corresponding to region 24, where there is conventional attached flow there is a similar order of drag reduction to graphs 30 and 31. In the transition region of flow 35, corresponding to region 25, the graph reflexes and the increase of drag reduction is indicated at 36, which is a region of vortex flow, corresponding to region 26. There is no flow breakaway, and thus no aircraft handling problems, and the relatively low drag reduction is acceptable because it is arranged to occur in other than aircraft cruising flight. Moreover, the relatively low bending moment increase is of vital importance since the main wing requires little or no strengthening.

In Figures 12 and 13, bar 40 indicates the design coefficient of lift point for efficient cruising flight, i.e. flight with a predetermined low level of drag, bar 41 indicates the design coefficient of lift point for the wing structure to be sufficiently strong to accommodate for example a 2½ g manoeuvre (it is usually a high speed design point) and bar 42 indicates the design coefficient of lift point at which stall can take place (it is a low speed design point). It is up to this latter point that good handling characteristics, that is to say controlled -non random - flow breakaway should be maintained.

Reverting now to Figures 1 and 3, these illustrate conventional attached flow over the winglets 2 in cruise lift coefficient conditions, the winglets are thus operating in the regions 24 and 34 illustrated in Figures 12 and 13.

Figures 2 and 4 illustrate the development of stable vortex flow in high lift coefficient conditions, the winglets 2 are thus operating in the regions 26 and 36 of Figures 12 and 13. As is illustrated, the vortices form over the inboard surface of an upper portion of the winglet and over an outboard surface of a lower portion of the winglet when the aircraft is in a generally straight and level flight attitude.

CLAIMS:

1. An aircraft wing including main wing means having a median plane and a wing tip region of specified chord having a leading edge region and a trailing edge region, and winglet means extending from said wing tip region, the winglet means having a root region with both a forward extremity and a rearward extremity in the region of the median plane, the forward extremity of the winglet means lying at or rearward of the leading edge region of the main wing means, a tip region remote from the median plane, a leading edge region extending between the forward extremity and the tip region of high sweep back over at least part of its length at or near the root region, and a trailing edge region extending between the rearward extremity of the root region and the tip region, the ratio of the square of the distance from the tip region to the root region to the area bounded by and including the root region, the tip region, the leading edge region, and the trailing edge region being 1.5 or less.

2. An aircraft wing according to Claim 1, wherein the winglet means includes twin tip regions, one lying above the median plane and one lying below each tip region having an associated leading edge region and trailing edge region.

3. An aircraft wing according to Claim 1 or Claim 2, in which the or each winglet leading edge region has a single

angle of sweepback set at between 85° and 50°.

4. An aircraft wing according to Claim 1 or Claim 2, in which the or each winglet leading edge region has at least two angles of sweepback, one near the root region being between 85° and 50°, to the median plane, and that and one nearer the tip region being at a maximum of 35° to the median plane.

5. An aircraft wing according to claim 4 wherein the or each leading edge region is of generally ogee planform and said two angles of sweepback respectively are at concave and convex parts of the ogee planform.

6. An aircraft wing according to Claim 3, or Claim 4, or claim 5 wherein the distance between the rearward extremity of the winglet root region and the trailing edge region of the wingtip is a maximum of 0.75 of the specified chord forward of said trailing edge region of the wingtip and is a maximum of 0.50 of the specified chord rearward of said trailing edge region.

7. An aircraft wing according to Claim 3, Claim 4, Claim 5, or Claim 6 wherein the distance between the extremities of the root region of the winglet is a maximum of 1.25 of the specified chord.

8. An aircraft wing according to Claim 2, in which both the upper and lower winglet leading edge regions have a single angle of sweepback at about 70°, to the median and wherein the Aspect Ratio for the combined upper and

lower winglet means is about 0.90.

9. An aircraft wing according to Claim 2, in which both winglet leading edge regions have at least two angles of sweepback, one nearer the root region being about 70° and one nearer the tip region being at about 45° and wherein the Aspect Ratio of the combined upper and lower winglet means is about 0.80.

10. An aircraft wing according to claim 9 wherein the leading edge regions are both of generally ogee planform and said two angles of sweepback respectively are at concave and convex parts of the ogee planform.

11. An aircraft wing according to Claim 8, wherein the distance between the rearward extremity of the winglet root region and the trailing edge region of the wingtip is about 0.05 of the specified chord rearward of said trailing edge region and wherein the distance between the extremities of the root region of the winglet is about 0.62 of the specified chord.

12. An aircraft wing according to Claim 9, or claim 10 wherein the distance between the rearward extremity of the winglet root region and the trailing edge region of the wingtip is about 0.05 of the specified chord rearward of said trailing edge region and wherein the distance between the extremities of the root region of the winglet is about 0.85 of the specified chord.

13. An aircraft wing according to any one of the previous

Claims, in which the winglet means lying above the median plane has the leading edge region and/or the trailing edge region cambered to cause a median line to droop in a direction outboard of the main wing means and in which the winglet means lying below the median plane has the leading edge region and/or the trailing edge region cambered to cause a median line to droop in a direction inboard of the main wing means. 14. An aircraft wing according to any one of the previous Claims, in which the root region of the winglet means is extended laterally inboard to provide fairing means.

Fig. 1.

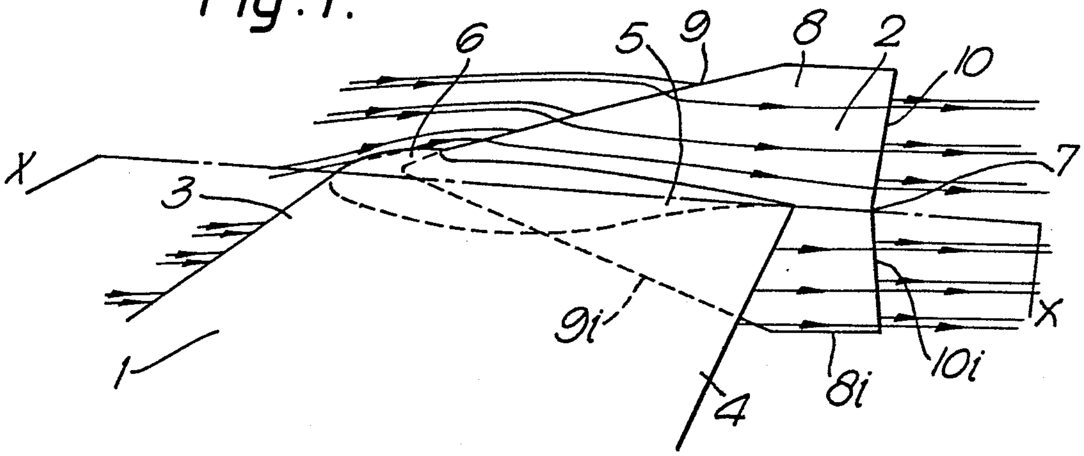


Fig. 2.

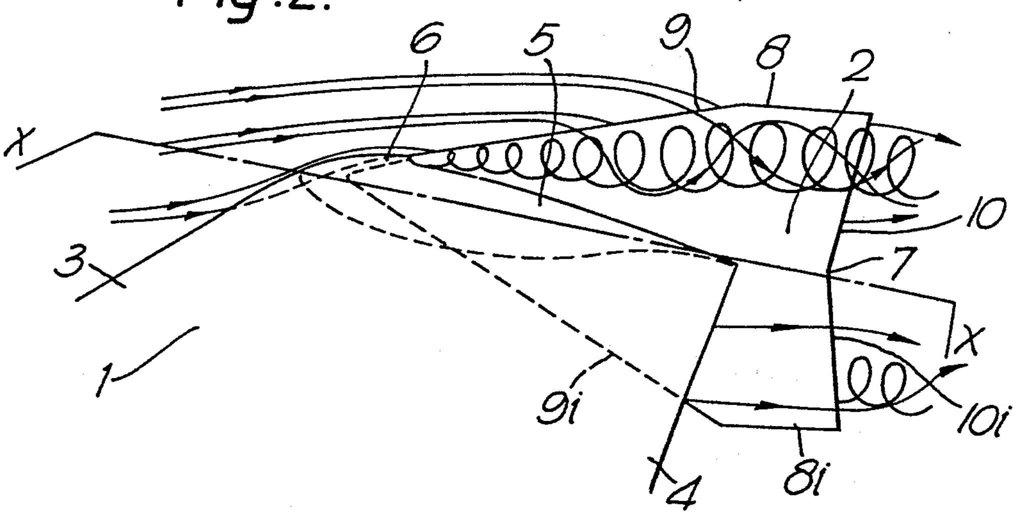


Fig. 11.

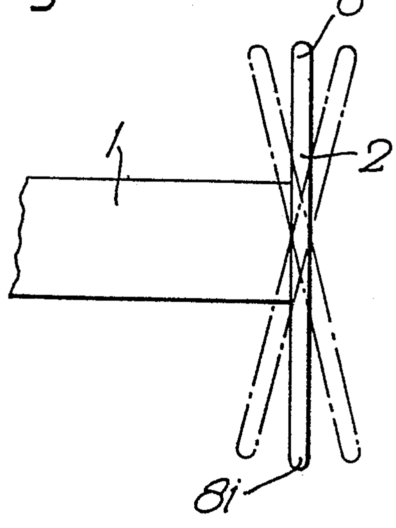


Fig. 3.

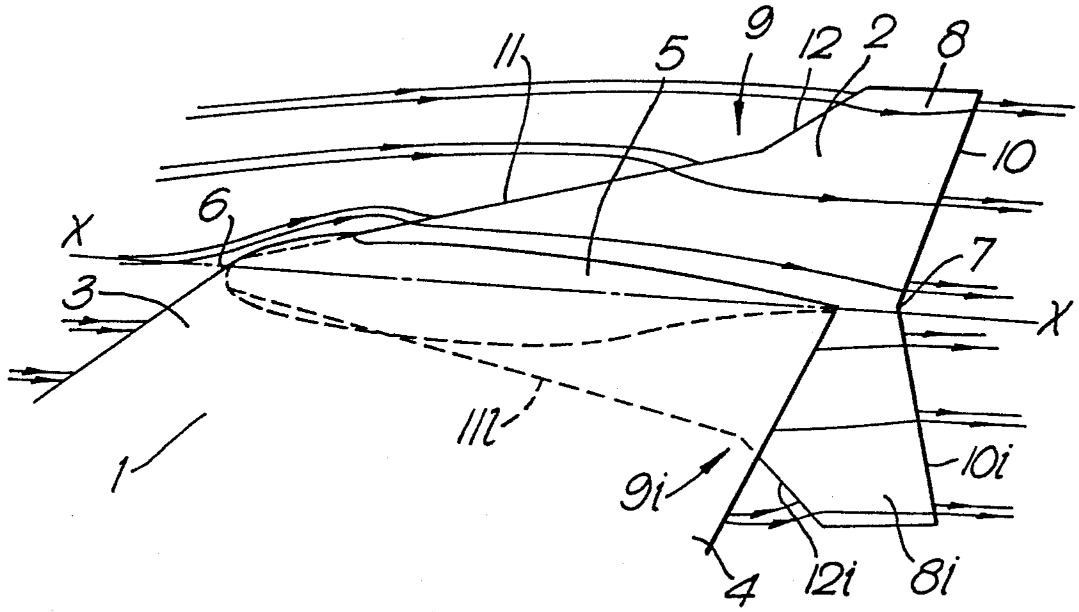
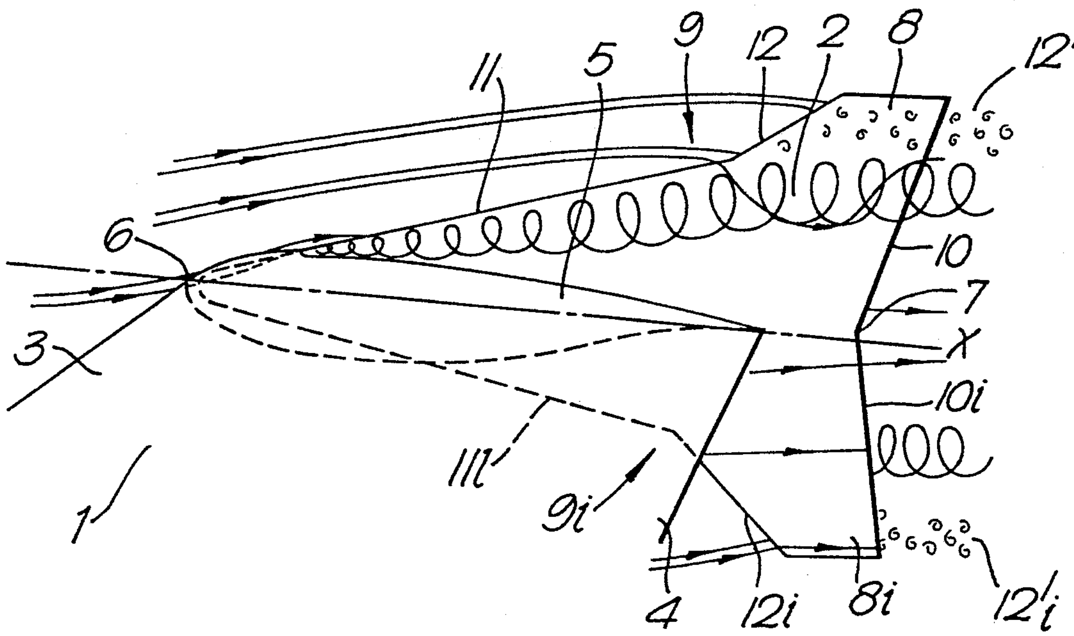

11
5
9
12
2
8
10
X
6
3
7
X
111
1
9i
10i
4
12i
8i

Fig. 4.


11
5
9
12
2
8
12'
6
10
7
3
X
10i
111
1
9i
4
12i
8i
12'i

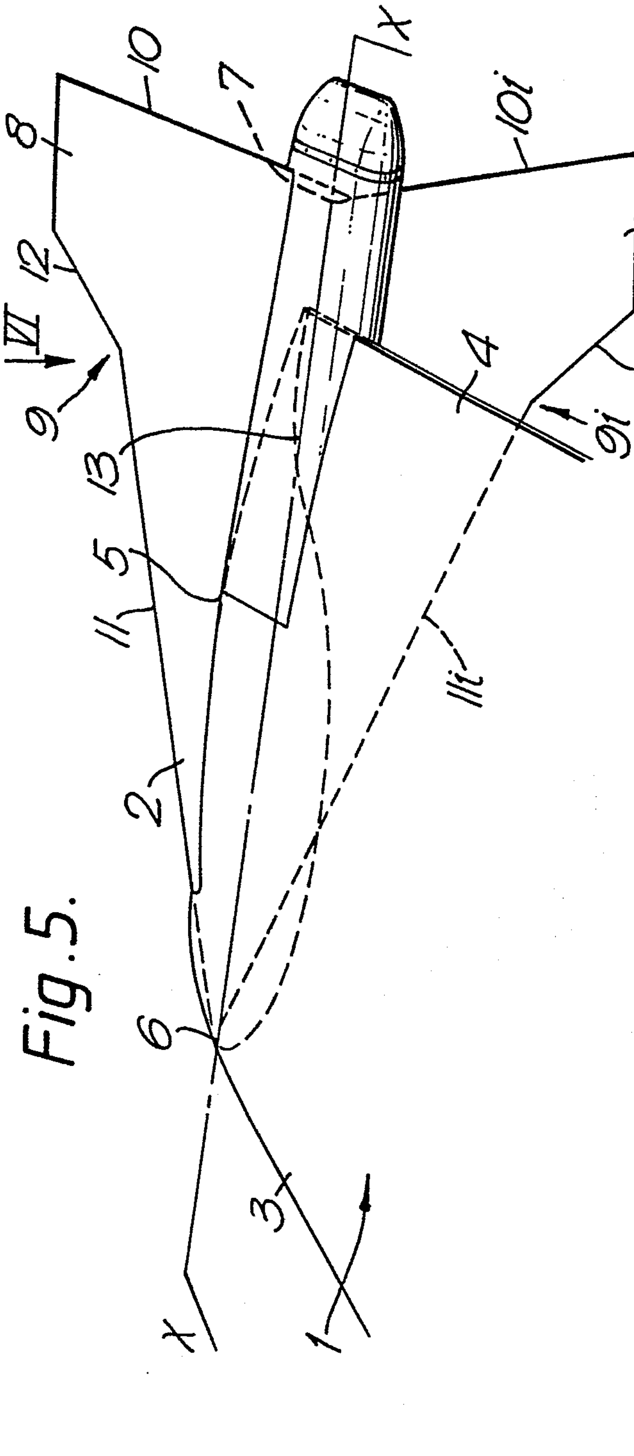

X
10
7
8
12
VI
9
13
5
11
2
6
3
1
X
10i
8i
12i
4
9i
11i

Fig.5.

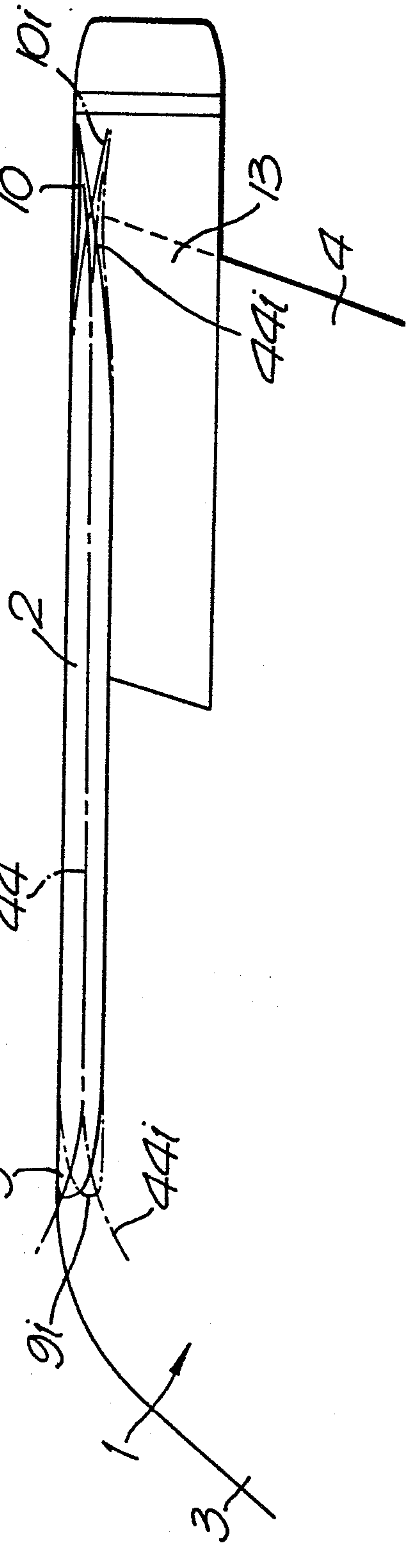

10i
10
13
4
44i
2
44
9
9i
44i
1
3

Fig.6.

Fig. 7.

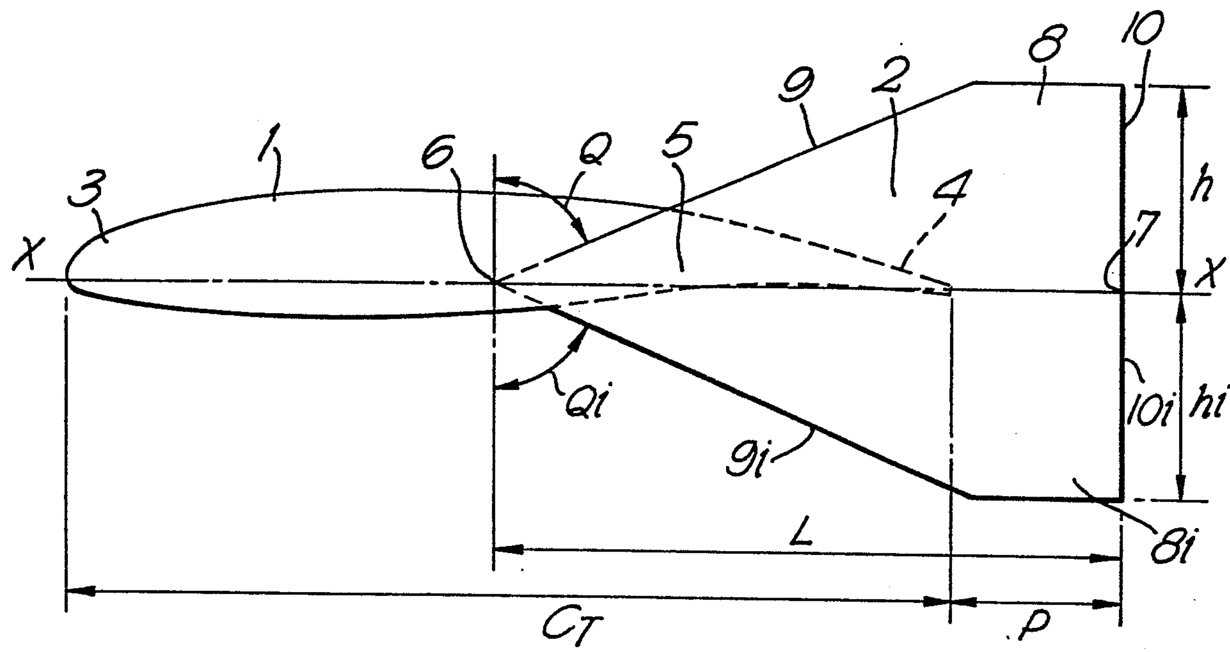

1
2
3
4
5
6
7
8
9
10
Q
Qi
9i
10i
8i
h
hi
X
X
L
C_T
P

Fig. 8.

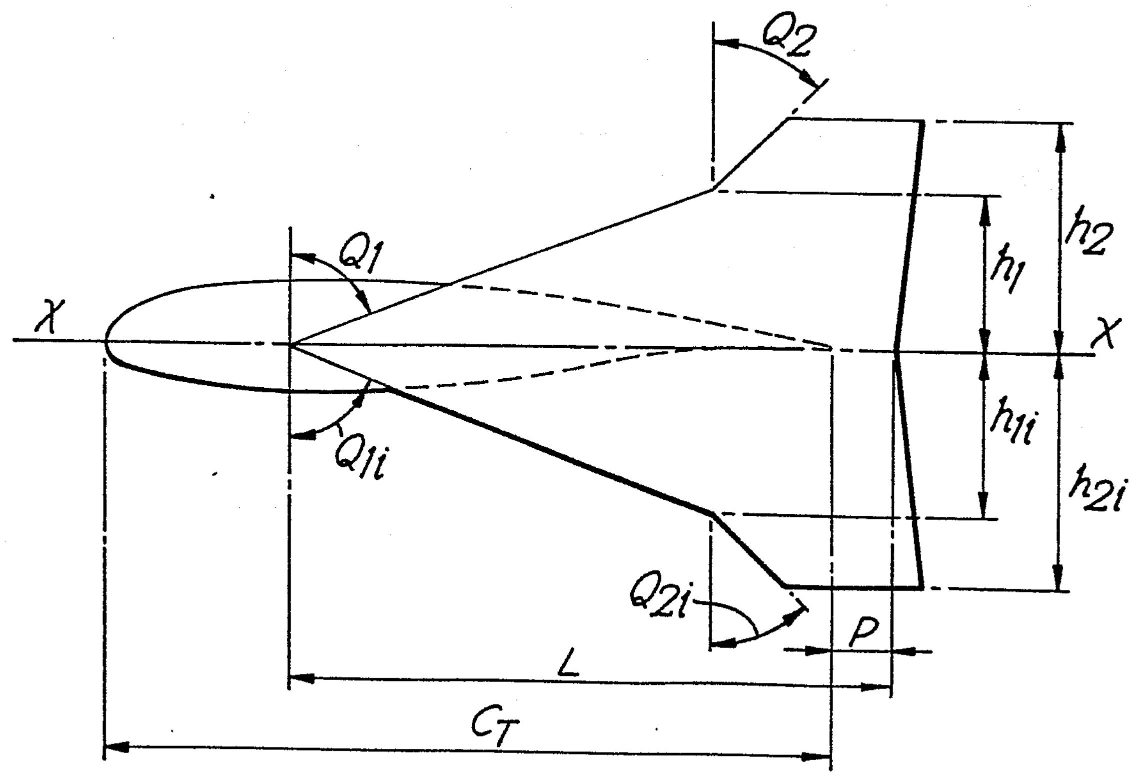

Q2
Q1
Q1i
Q2i
X
X
h1
h2
h1i
h2i
P
L
C_T

Fig. 9a.

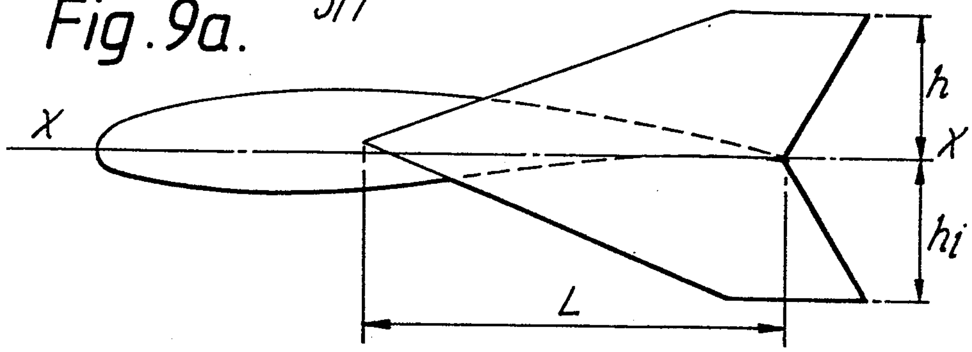


Fig. 9b.

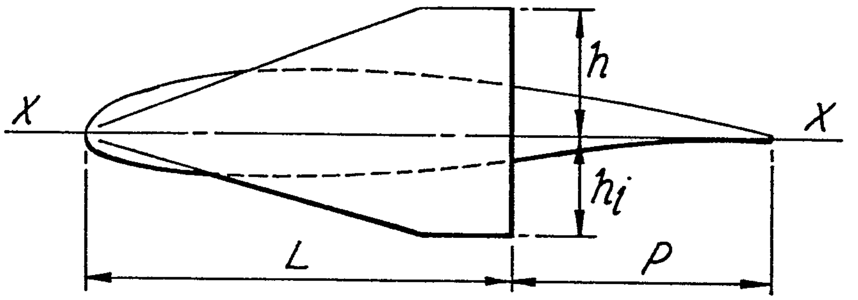


Fig. 9c.

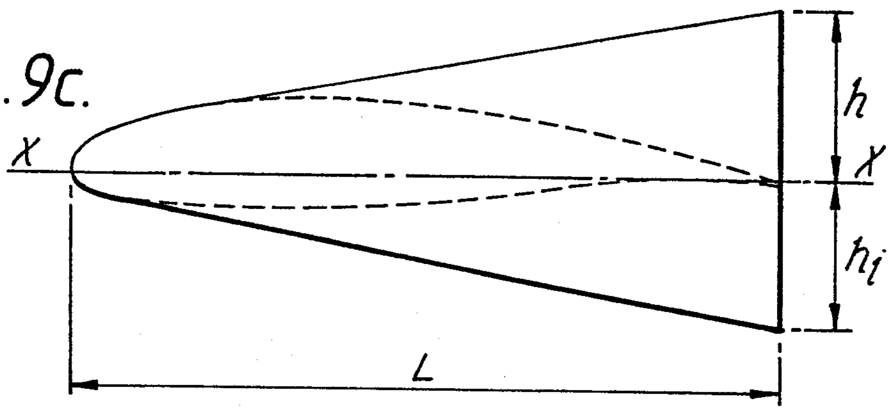


Fig. 10.

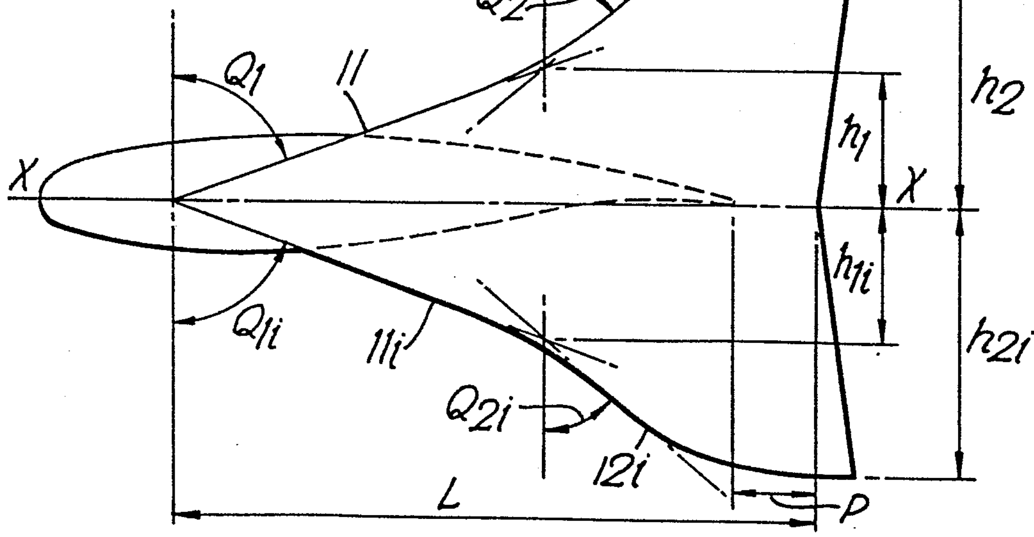


Fig.12.

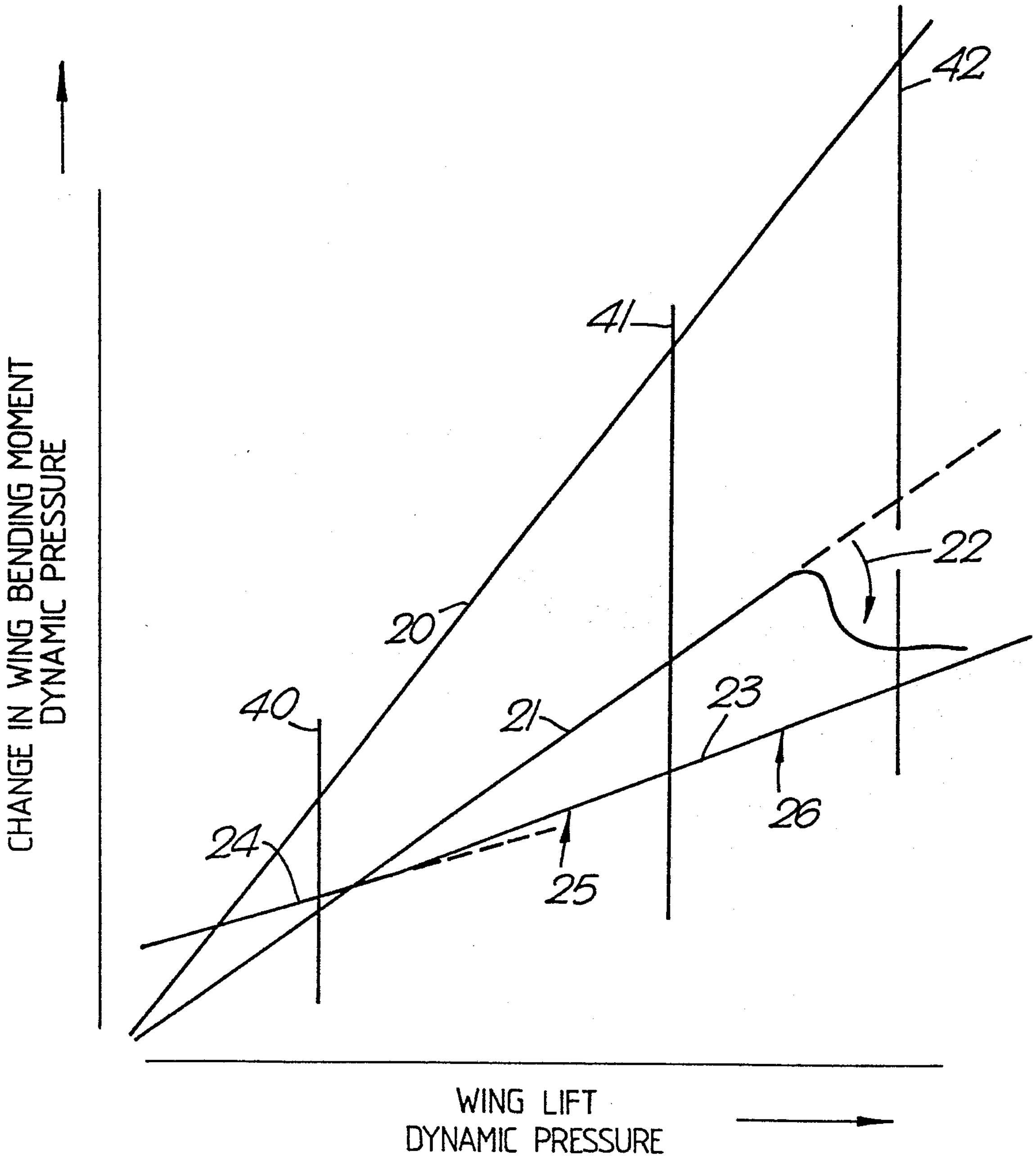
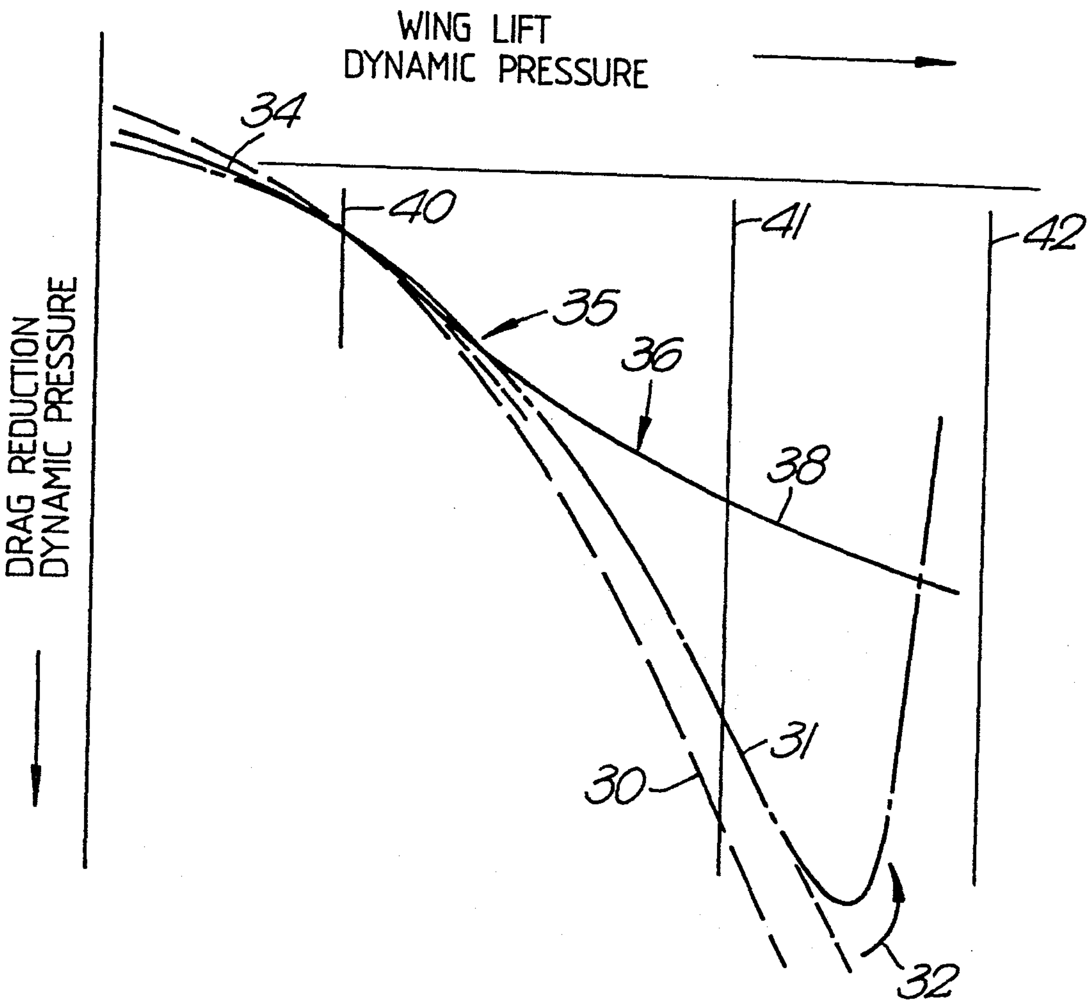

CHANGE IN WING BENDING MOMENT
DYNAMIC PRESSURE
42
41
22
20
40
21
23
24
26
25
WING LIFT
DYNAMIC PRESSURE

Fig.13.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DYNAMIC PRESSURE
DRAG REDUCTION
DYNAMIC PRESSURE
34
40
41
42
35
36
38
31
30
32

0122790

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 84 30 2531

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
			B 64 C 23/06
Y	US-A-2 576 981 (VOGT) * Column 1, lines 43-59; column 3, line 32 - column 4, line 27; figures 3-7 * ---	1,2,13	
Y	DE-A-2 637 461 (KNOCHE) * Page 3, lines 7-15; page 4, lines 23-28; figure 1 * ---	1-3	
A	FR-A-2 355 188 (NATIONAL RESEARCH DEVELOPMENT CORP.) * Page 1, lines 1-7; page 5, lines 5-12; page 7, line 38 - page 8, line 4; figures 3,7,10 * ---	1,14	
P,A	EP-A-0 094 064 (RASMUSSEN) * Whole document * -----	1,2,14	TECHNICAL FIELDS SEARCHED (Int. Cl. 3)
			B 64 C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	05-07-1984	ZERI A.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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